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Status Report

DEVELOPMENT OF SURFACTANTS AS PROFILE MODIFICATION AGENTS

Project OE3, Milestone 4, FY87

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SUMMARY

The FY87 Annual Research Plan for project OE3 called for a scoping study to evaluate the potential of using surfactants for profile modification. This status report is a summary of the progress on the four tasks in this project. In FY88, the research will be conducted and a topical report will be prepared describing the results of the entire project. This topical report will be completed by February 1988.

The goal of this research was to develop a profile modification system that will provide in-depth preferential penetration into the highly permeable zones that have been swept by water and thus provide improved sweep efficiency.

A series of amine oxide-alcohol blends have been screened by monitoring their viscosity as the ratios of components are varied. Blends were selected that would chromatographically separate as they pass through reservoir rock leaving highly viscous surfactant gels to block pore throats, thus reducing the flow of fluid through the channel.

Successful diversion of water has been obtained in cores of different permeability, when connected in parrallel, using both 1-ft and 4-ft cores. All cores were individually oil saturated; the high- and low-permeability cores were connected to a common injection source and were waterflooded, with production from each core individually monitored. The high-permeability cores produced oil, whereas the low-permeability cores did not. The addition of a low-viscosity amine oxide-alcohol blend to the waterflood caused a reduction in brine permeability in the high-permeability core. A small pressure increase in the system resulted and the low-permability core started to produce oil and was subsequently waterflooded. Extension of these experiments to 40-ft parallel slim tube experiments with pressure ports along the tube has been unsuccessful. The 316 stainless steel showed significant corrosion because of the high-salinity brine. This failure is believed to result from soluble iron ions catalytically decomposing the amine oxide to a secondary amine. The pressure trace along the core showed migration of the slug and reduction in permeability; however, no demonstration of in-depth preferential profile modification was observed in the slim tubes.

For the work in FY88 we will use Monel tubing to conduct the in-depth profile modification using an amine oxide-alcohol blend.

TECHNICAL PROGRESS

The progress that has been made in this project is as follows.

A series of five amine oxides, PF-1 thru PF-5, based upon commercially available amine oxides, have been mixed with short-chain, water-soluble alcohols from methanol to isoamyl alcohol in a brine that corresponds to that of produced water from North Burbank field, Osage County, Oklahoma. The composition of the brine is 86,130 ppm TDS and is representative of many mid-continent reservoirs having high salinity, high divalent ion concentration, and moderate temperatures.

Stability and viscosity for a series of blends of these amine oxides and alcohols were determined from bottle tests and from measurements of their viscosity using a Brookfield LVT viscometer at 50° C. From high performance liquid chromatography, HPLC, a rough order of elution from a silica gel column was obtained by the use of a mixed solvent system of methanol, water and acetonitrile. As an example, the order of elution of PF-1 with alcohols was found to be methanol, ethanol, propanol, isopropanol, PF-1, isobutanol, and isoamyl alcohol. The order of elution provided only a relative ordering of chromatographic separation since the column did not contain a hydrocarbon phase such as crude oil, nor was the eluant a brine that could be used for a waterflood. Phase-inversion-temperature (PIT) measurements were conducted on several of the formulations to help avoid the formation of oil-in-water emulsions when this surfactant-alcohol blend contacts crude oil at the reservoir test conditions of 50° C. North Burbank Unit (NBU) stock tank oil was used in both PIT and oil-displacement experiments.

The first displacement test used two 10-in. unfired Berea sandstone cores with different permeabilities that had been individually saturated with NBU brine and NBU crude oil (Fig. 1). Waterflooding (frontal advance rate of 0.5 ft/day) these cores in parallel (common brine source) produced oil from the high-permeability core (820 md) but none from the 176 md core. An 8-percent PV slug containing 4 percent PF-2 and 5 percent isopropyl alcohol in NBU brine was injected followed by continuous injection of NBU brine. The pressure increased by less than 0.1 psi (100 psi pressure transducer) during injection of the surfactant slug and waterflood. Oil and brine started to be produced from the low-permeability core, and the rate of water being produced from the high permeability core decreased, as shown in figure 2. After the low-permeability core was waterflooded to residual oil saturation, brine permeability of the high-permeability core was 136 md (an 83% reduction in permeablity). The experiment showed the necessity of using more sensitive pressure transducers, along the path of the flood, and determining the changes in relative permeabilities during the flood test.

Figure 3 shows schematically the configuration of parallel slim tubes used to evaluate whether the amine oxide-alcohol blend was capable of diversion in depth, well away from the injector. The design evolved to mitigate problems encountered when fines migrated to restrict fluid near the end porous filter (15 micron), which created the largest pressure drop in the system.

The initial 40-ft slim tube experiment was packed with fine quartz sand which proved ineffective in chromatographically separating the PF-2-isopropyl alcohol slug. Only a small slug of tertiary oil was recovered from the high-permeability tube, and no oil was produced from the low-permeability tube.

The stainless steel slim tubes were repacked with crushed, sieved Berea sandstone where permeability contrasts were obtained by packing the column with Berea of different mesh size. The fine fractions which contain a significant fraction of clays was excluded. The injected slug formulation was altered and injected as a surfactant-alcohol slug followed by a slug of brine and the sequence was repeated several times. The steps complicated the pressure trace, as is shown in figures 4 and 5, but did not conclusively show in-depth profile modification.

The slim tube experiments including saturation, permeability measurements, oil saturation, waterflooding, surfactant-alcohol slug injection additional water injection to displace the chemical slug, followed by solvent injection to clean the tube requires 8 weeks, and thus a second set of parallel slim tubes was constructed to accelerate the research.

The latest test in this series used a 10-percent PV slug of 5 percent PF-2 and 7.5 percent ethanol displaced by NBU brine. Little pressure buildup was noted in the pressure trace, and analysis of the effluent 2 weeks after completion of the test showed ethanol, PF-2, and a secondary amine, the degradation product of the amine oxide. Shortly after the completion of this displacement test, the stainless steel slim tubes were cleaned but burst upon saturation with NBU brine. Numerous points of corrosion were observed, and the inside of the tube was heavily rusted. We concluded that soluble iron due to corrosion had catalytically decomposed the amine oxide to a secondary amine under the test conditions. The surfactant manufacturer has recommended the use of Monel tubing to avoid this reaction.

RECOMMENDATIONS FOR FURTHER RESEARCH

Because this project was a scoping study with the goal of showing that an amine oxide-alcohol blend could be placed at depth and provide profile modification and because this has not been shown, we recommend that near-term research be directed to show profile modification in the Monel slim tubes. Based upon the industrial funds remaining there should be enough funds to complete one run in the Monel slim tubes and prepare a topical report.

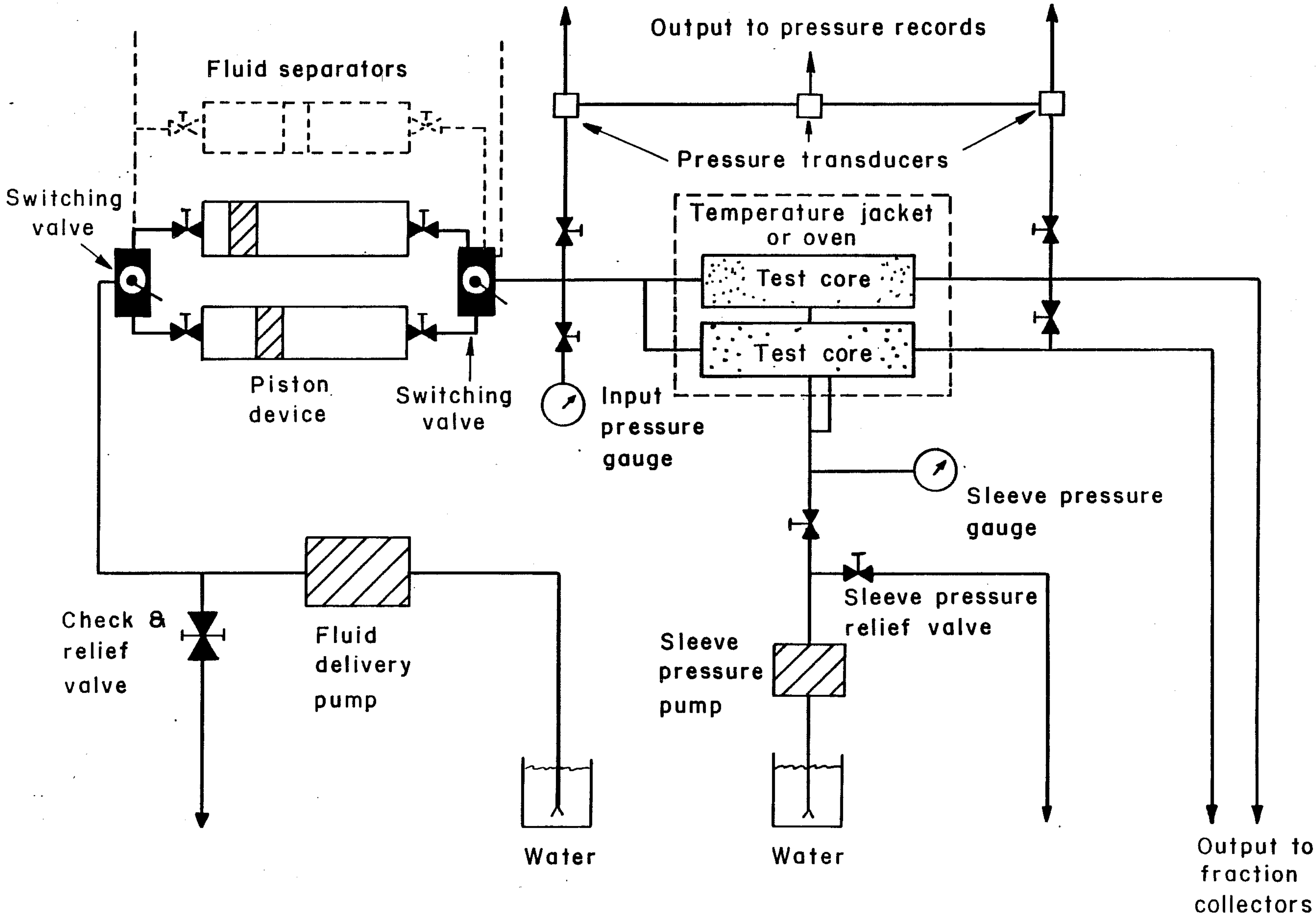

FIGURE 1. - Schematic of parallel corefloods.

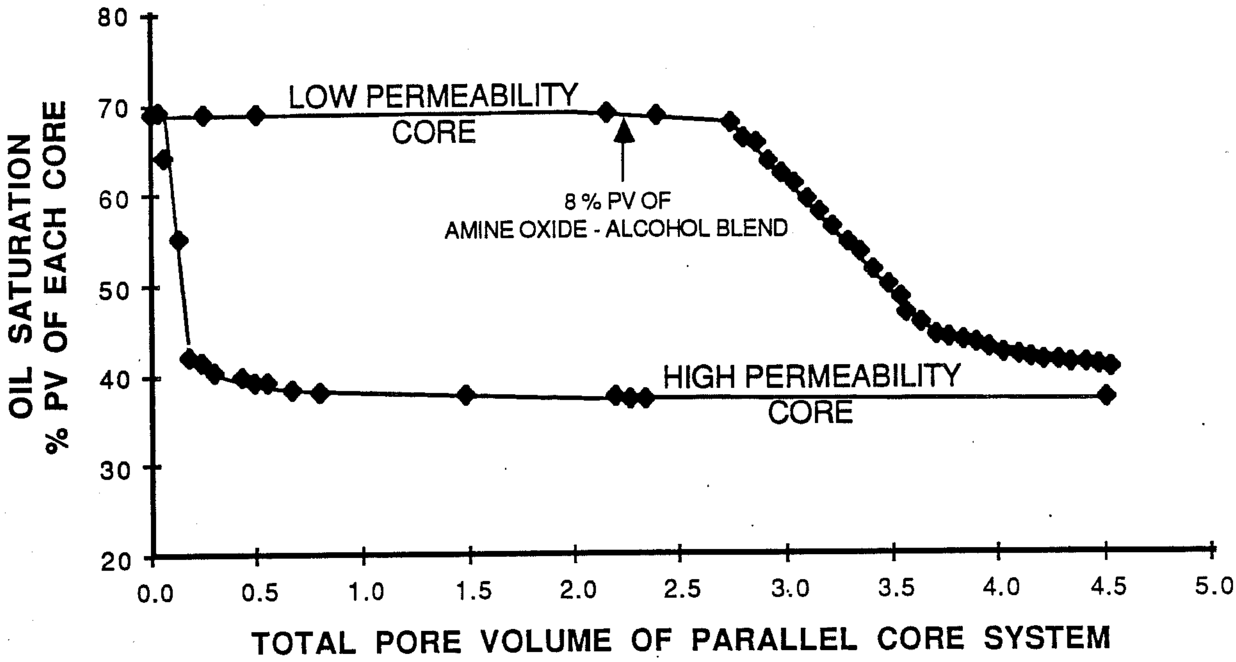

FIGURE 2. - Oil recovery from 10-in. (820 md and 176 md) Berea sandstone cores flooded in parallel.

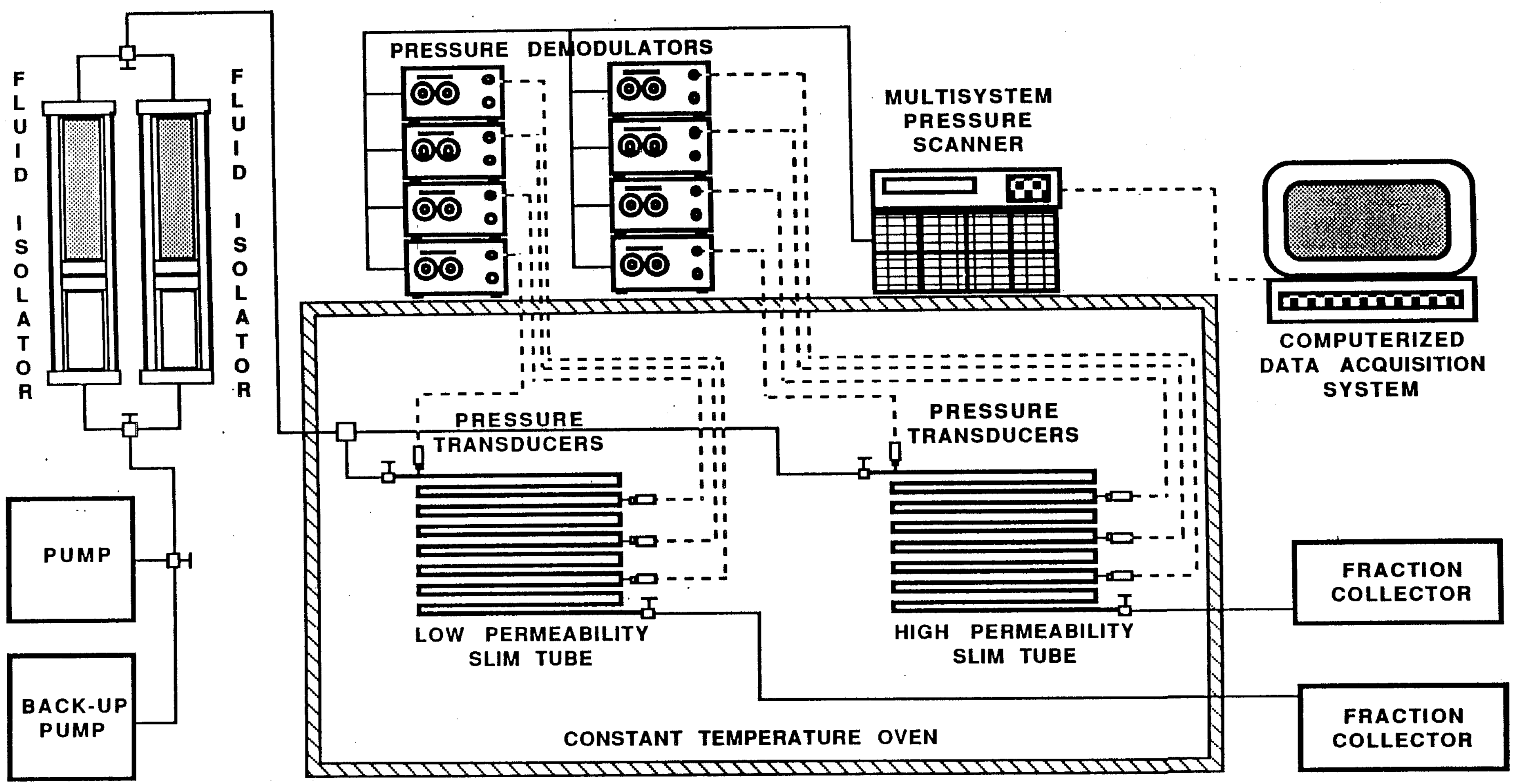

FIGURE 3. - Schematic of parallel slim tubes.

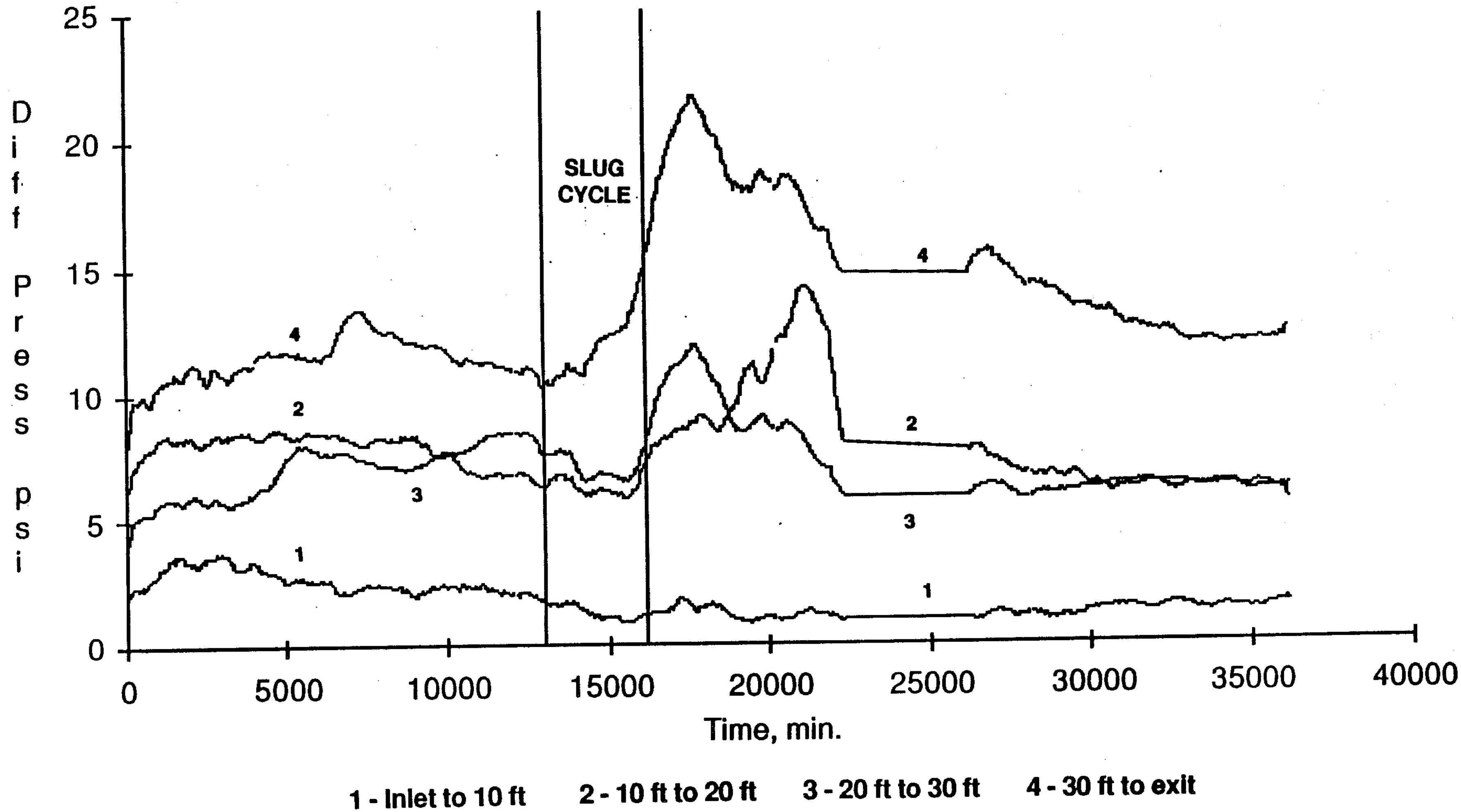

FIGURE 4. - Differential pressure trace vs. time in minutes for the low-permeability slim tube before, during, and after injection of amine oxide-alcohol slug.

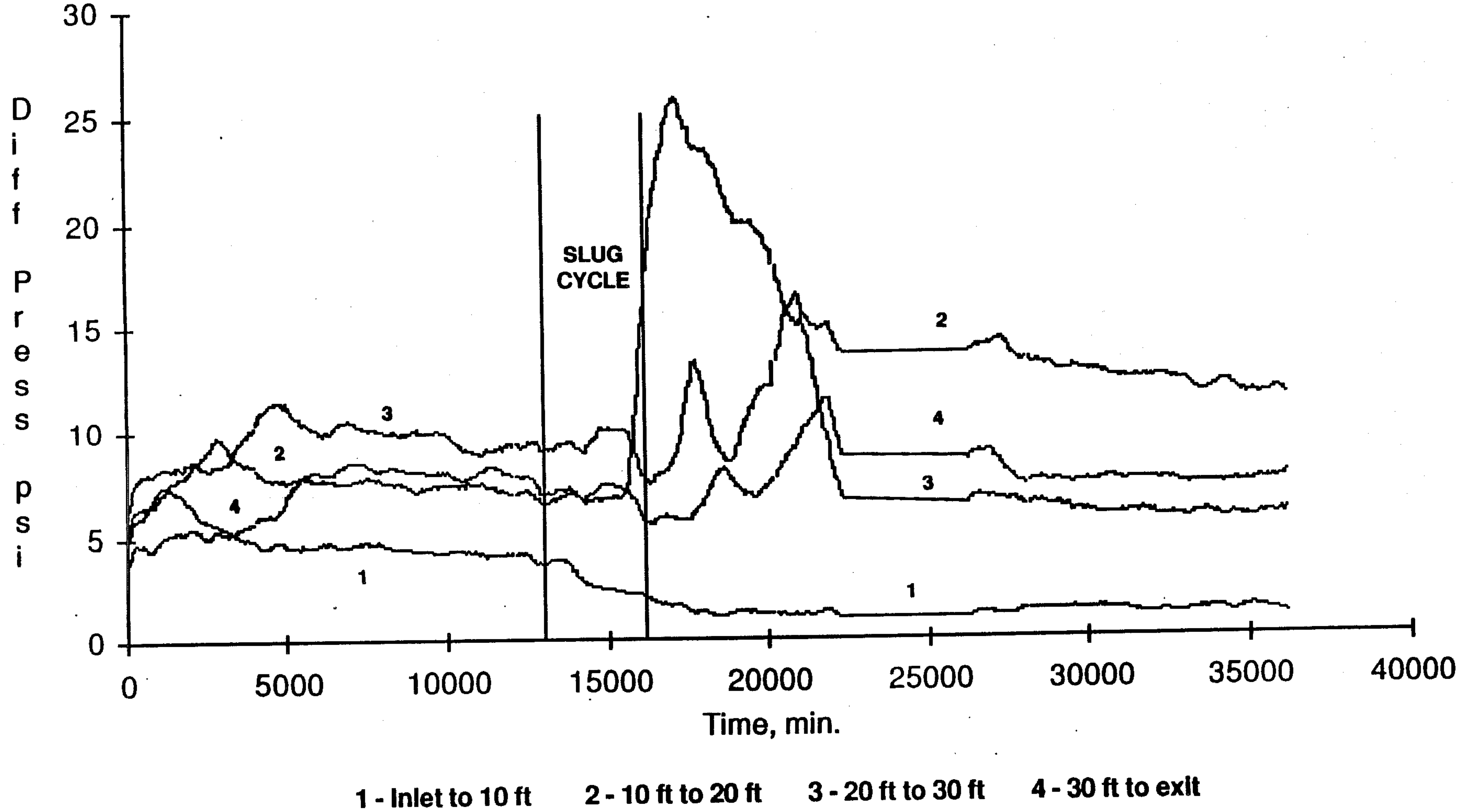

FIGURE 5. - Pressure trace of high permeability slim tube before, during, and after injection of the amine oxide-alcohol slug.